

Bond University  
Research Repository



## The impact of environmental regulations on urban Green innovation efficiency: The case of Xi'an

Zhang, Jingxiao; Kang, Le; Li, Hui; Ballesteros-Pérez, Pablo; Skitmore, Martin; Zuo, Jian

*Published in:*  
Sustainable Cities and Society

*DOI:*  
[10.1016/j.scs.2020.102123](https://doi.org/10.1016/j.scs.2020.102123)

*Licence:*  
CC BY-NC-ND

[Link to output in Bond University research repository.](#)

*Recommended citation(APA):*  
Zhang, J., Kang, L., Li, H., Ballesteros-Pérez, P., Skitmore, M., & Zuo, J. (2020). The impact of environmental regulations on urban Green innovation efficiency: The case of Xi'an. *Sustainable Cities and Society*, 57, [102123]. <https://doi.org/10.1016/j.scs.2020.102123>

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

For more information, or if you believe that this document breaches copyright, please contact the Bond University research repository coordinator.

# 1        **The Impact of Environmental Regulations on Urban Green**

## 2                                **Innovation Efficiency: the Case of Xi'an**

3                                Jingxiao Zhang<sup>a\*</sup>, Le Kang<sup>b</sup>, Hui Li<sup>c</sup>, Pablo Ballesteros-Pérez<sup>d</sup>,

4    Martin Skitmore<sup>e</sup>, Jian Zuo<sup>f</sup>

5        <sup>a</sup> School of Economics and Management, Chang' an University, Xi'an, P.R. China,  
6        710064. Email: [zhangjingxiao964@126.com](mailto:zhangjingxiao964@126.com) (*Corresponding author*)

7        <sup>b</sup> School of Economics and Management, Chang' an University, Xi'an, P.R. China,  
8        710064. Email: [kanglehard00@163.com](mailto:kanglehard00@163.com)

9        <sup>c</sup> School of Civil Engineering, Chang' an University, Xi'an, P.R. China, 710064.  
10        Email: [lihui9922@chd.edu.cn](mailto:lihui9922@chd.edu.cn)

11        <sup>d</sup> Departamento de Ingeniería Mecánica y Diseño industrial, Escuela Superior de  
12        Ingeniería, Universidad de Cádiz, Spain. Email: [pablo.ballesteros@uca.es](mailto:pablo.ballesteros@uca.es)

13        <sup>e</sup> School of Civil Engineering and the Built Environment, Queensland University of  
14        Technology (QUT), Brisbane, Australia; Faculty of Computing, Engineering and the  
15        Built Environment, Birmingham City University, Birmingham, UK. Email:  
16        [rm.skitmore@qut.edu.au](mailto:rm.skitmore@qut.edu.au)

17        <sup>f</sup> School of Architecture & Built Environment, The University of Adelaide, Adelaide,  
18        Australia. Email: [jian.zuo@adelaide.edu.au](mailto:jian.zuo@adelaide.edu.au)

# 19        **The Impact of Environmental Regulations on Urban Green**

## 20                                **Innovation Efficiency: the Case of Xi'an**

### 21        **Abstract**

22                While balancing economic progress and environmental pollution, environmental  
23 regulation plays a vital role conditioning green innovation. However, most research  
24 focuses on the effect of such regulations at the industry- or regional-level, lacking city-  
25 level analysis. Using the city of Xi'an (China) as a case study, environmental  
26 regulations and their effect on urban green innovation are analysed. First, using a  
27 slacks-based measure of directional distance functions (SBM-DDF) model we measure  
28 the green innovation efficiency of Xi'an from 2003 to 2016. Regression analysis is then  
29 used to explore the green innovation effect under the implementation of three  
30 environmental regulations, including command-and-control, market-based, and  
31 voluntary. Results indicate that market-based and voluntary regulations are more  
32 efficient at stimulating green innovation than command-and-control environmental  
33 regulations. The environmental regulations and green innovation efficiency also have  
34 non-linear inverted U-shape relationships. The findings will help policy makers to  
35 design more effective environmental regulations.

### 36        **Keywords**

37                Environmental regulation, urban green innovation efficiency, SBM-DDF model,  
38 undesirable output, regression analysis

### 40        **1. Introduction**

41                Higher industrialization has contributed to the development of many urban  
42 economies, but this also has brought some environmental problems. Balancing a city's  
43 economic progress and its environmental preservation has been an important topic in

44 the field of sustainable development for a long time. Of the indices used for measuring  
45 a region's sustainable development ability, one of the most prominent is green  
46 innovation (Liu, 2015; Bai, 2012; Zuo et al., 2012). This index reflects an urban  
47 economy's sustainable competitive advantage.

48 Innovative urban development not only involves technological progress, but also  
49 the development of the environment. Similarly, cities, being accountable for a large  
50 proportion of total gas emissions, are usually among the first to adopt innovative  
51 sustainable practices that protect the environment (Dong et al., 2014; Yu et al., 2018).  
52 *Urban green innovation* involves a wide range of urban innovative activities aimed at  
53 stimulating a city's greener sustainable development. Urban green innovation can help  
54 cities gain an absolute competitive advantage for their economy (Fei et al., 2016; Ryan,  
55 2018). These may be some reasons why scholars are paying increasing attention to  
56 urban green innovation (Yang and Wang, 2009; OECD, 2011).

57 From a socio-political perspective, the sustainable development of a city is also  
58 related to a complex mechanism generated by the interaction of politics, economy and  
59 culture (Cumò et al., 2012; Morris et al., 2018). The socio-political behavior is very  
60 important in the process of building a green innovative city. The government takes  
61 political actions to push urban green development forward and must ensure the  
62 effectiveness of policies implementation. Namely, the goals of environmental  
63 regulations are transformed into specific strategies and institutionalized (Sum, 2005).  
64 Hence, urban environment and green innovation development are dealt with through  
65 regulatory incentives and policy frameworks (Bibri and Krogstie, 2016). Political  
66 action has a wide variety of political mechanisms and governance arrangements. They  
67 support and stimulate the role of environmental regulations in urban green innovation  
68 in different ways, such as: formulating policy tools and incentives to achieve urban

69 change, authorizing specific organizations to legalize research activities, promoting  
70 government participation to achieve capital and market incentives, funding education  
71 and research institutions for the dissemination and utilization of knowledge and  
72 technology related to urban development, etc. (Bibri, 2015). All these create a favorable  
73 environment for urban innovation and promotes sustainable urbanization.

74 Therefore, many studies agree that effective environmental regulations can  
75 promote the sustainable development of a city, rectify undesirable externalities as  
76 environmental pollution, and stimulate green innovation within the industry (Yuan et  
77 al., 2016; Nesta et al., 2012). The latter is generally achieved by incorporating some  
78 degree of innovation in technology and its products, and realizing win-win ecological,  
79 social, and economic outcomes (Mickwitz et al., 2008; Ambec et al., 2013). However,  
80 different environmental regulations exist varying effectiveness on green innovation  
81 (Zhang et al., 2018). Meanwhile, characteristics of the host country and its contextual  
82 factors are also influential (Bergek and Berggren, 2014; Ren et al., 2016).

83 China is a country whose government has been recently passing many laws to  
84 stimulate more sustainable development, such as the Urban Greening Ordinance  
85 (revised in 2017), the Circular Economy Promotion Law (2009), and the Environmental  
86 Protection Law (revised in 2014). However, as with many other countries, China could  
87 fail in its attempt to stimulate a greener economy. India, for example, passed the  
88 Environmental Protection Act (1986), Air Act (1987 revision), and Water Act (1988  
89 revision), and counts on a National Green Tribunal. However, that country's lack of a  
90 comprehensive environmental regulatory approach and critical evaluation of  
91 performance ended with citizens still suffering nowadays from many environmental  
92 problems (see Mejia, 2009). Hence, it seems obvious that it is not enough to seek green  
93 innovation just by passing environmental laws.

94 Extensive research has also been carried out on the innovation mechanisms behind  
95 environmental regulations. Most of them focus on processes and product innovation of  
96 some industries, and the role of environmental regulations in them (e.g. Guo et al., 2019;  
97 Tang et al., 2019). For example, research on green innovation has traditionally focused  
98 on economic and ecological innovation in the medium and macro levels such as the  
99 industrial level and the national level (Wang and Zhang, 2019; Khan et al., 2019). It has  
100 also focused on the micro level, such as company and product level (Borsatto and Amui,  
101 2019; Liao, 2018). However, little research has been conducted on the relationship  
102 between different environmental regulation and green innovation from the urban  
103 perspective (city level of analysis).

104 Xi'an has been for a long time a Chinese paradigm of a city trying to stimulate  
105 innovative practices. The vast number of actions undertaken and the central position it  
106 occupies in China makes of Xi'an a representative example for analysis. Hence, the  
107 case study of Xi'an is analyzed to compare the effect on urban green innovation brought  
108 by different environmental regulations.

109 The structure of this paper is as follows. The next section reviews the research  
110 literature. In section 3, the index system, data sources, and analysis model for  
111 representing the regression variables are described in detail. The next two sections 4  
112 and 5 describe and analyze the empirical results, respectively. Section 6 deals with  
113 policy recommendations, and section 7 describes the conclusions and implications of  
114 this study.

## 115 **2. Literature review**

### 116 **2.1 Urban green innovation**

117 In innovation research, green innovation is crucial to social development and the  
118 transformation of urban environments (Fei et al., 2016). Green innovation is often

119 connected with ecological modernization, sustainable development, and other  
120 environmental issues (Schiederig et al., 2012). Green innovation does not just mean  
121 reducing environmental problems, but also generating significant environmental  
122 benefits (Driessen and Hillebrand, 2002). Fussler and James (1996) were among the  
123 first to refer to it, emphasizing that green innovation drivers could explain the lack of  
124 innovation vitality of many companies. Kemp et al. (1998) later defined green  
125 innovation as "new or improved processes, technologies, systems, and products  
126 resulting from avoiding or reducing environmental damage". This is now a commonly  
127 accepted definition, despite it is constrained to a micro-enterprise perspective. Chen et  
128 al. (2006) also analyzed the green innovation of products and manufacturing processes.  
129 Nowadays, green innovation also encompasses social and institutional innovation,  
130 including public participation, institutional structures, and the education system  
131 (CCICED, 2008).

132 Urban green development, on the other hand, is identified by many as the analysis  
133 of pollutant emissions and energy resource constraints (Glaeser and Kahn, 2010; Ji et  
134 al., 2017). Similarly, but from an innovation perspective, many papers have also  
135 focused on the construction of innovative cities or green development index systems  
136 (e.g., the GIE) as well as on the assessment of urban innovation ability (e.g. R&D  
137 funding, education and economy performance, technological innovative capabilities,  
138 etc.) (Liu, 2015; Sun et al., 2018).

139 In what follows, stemming from the dominant input-output approach of most  
140 research into innovation, it is assumed that urban green innovation aims at obtaining  
141 more economic benefits, technological progress, and greener city spaces with the same  
142 (or lower) investment in economic capital, human resources, energy, and pollutant  
143 emissions. By this definition, urban green innovation pursues the maximization of

144 economic, social, and environmental benefits, while promoting sustainable urban  
145 development.

## 146 **2.2 Types of environmental regulation**

147 Environmental regulation is generally understood as the concretization of a  
148 sustainable development and environmental protection strategy (Chen and Härdle,  
149 2015). It provides the guidelines for restraining and coordinating the perception, uses,  
150 and aims of environmentally-regulated objects. It can also effectively improve  
151 environmental quality, while also offsetting the regulatory costs arising from pollution  
152 control (Ribeiro and Kruglianskas, 2015). In general, environmental regulations are  
153 classified into three groups: command-and-control, market-based, and voluntary (Ren  
154 et al., 2018).

155 From a regulatory and mandatory perspective, command-and-control regulations  
156 involve legislation that states what is permitted and what is illegal. They include  
157 environmental laws and regulations, product and technical standards, bans, and  
158 environmental assessment systems. This type of regulation is widely used in China.

159 Market-based regulation means that government uses prices as a market-oriented  
160 mean to achieve higher pollution control efficiency at a lower cost. From this  
161 perspective, environmental regulations include environmental taxes and fees, subsidies,  
162 market bonds, emissions trading, and ecological compensation systems.

163 Finally, from the perspective of participation mechanisms, voluntary  
164 environmental regulations provide important instruments of regulation through public  
165 participation. These include information disclosure, environmental labels,  
166 environmental letters and visits, and transparent publicity, to cite a few.

## 167 **2.3 Research gap**

168 Despite the importance of environmental regulation is widely recognized and



169 researched, most research analyses have concentrated on the innovation effect of  
170 environmental regulations at the enterprise or industry level. Research on how  
171 environmental regulations promote the development of green innovation in urban  
172 settings is still relatively scarce. It is anticipated that different environmental  
173 regulations can promote different green innovation efficiency outcomes too. However,  
174 it is unclear what these relationships might be like, especially when previous results  
175 from the industry and enterprises are sometimes contradictory.

176 Xi'an has experienced significant economic and innovation changes over the last  
177 15 years. Hence, it is an exemplar likely to constitute a very interesting and  
178 representative case study. Consequently, Xi'an is used to explore the effects on urban  
179 green innovation efficiency of the three broad groups of environmental regulation  
180 (command-and-control, market-based, and voluntary).

### 181 **3. Materials and methods**

182 This study uses an explanatory case study to analyze the relationship between  
183 environmental regulation and urban green innovation. It also resorts to Data  
184 Envelopment Analysis (DEA) and regression techniques for deeper data analysis. Some  
185 robustness tests are also implemented to test the results validity. The purpose and  
186 implementation of each of them will be outlined as they are introduced.

#### 187 **3.1 Case study**

188 A case study is a common empirical research method, which can comprehensively  
189 investigate complex and specific problems in the reality (Yin, 2007). Particularly,  
190 explanatory case studies aim at summarizing phenomena and extract some conclusions  
191 which are suitable for a first relevance or causality analysis (Eisenhardt, 1989).

192 Here, we selected Xi'an to analyze green innovation and the effects of  
193 environmental regulation in it. Xi'an is one of the top ten innovative cities in China

194 (Meng, 2018). It has 63 colleges and universities, 3000 scientific research institutions,  
195 and over 40 national laboratories employing more than 460,000 professional and  
196 technical personnel (Meng, 2018). The city has introduced many policies in recent years  
197 to stimulate innovation and entrepreneurial development. These policies have  
198 contributed to the construction of innovation platforms (Li et al., 2018b). The 2018  
199 China Urban Innovation Competitiveness Development Report (Huang, 2018) ranked  
200 Xi'an's urban innovation competitiveness eighth in the country, being one the most  
201 innovative cities compared to other cities located in central and western regions.  
202 Meanwhile, much literature has described Xi'an as a city to carry out research on  
203 technological innovation (Wang and Zhou, 2015; Li et al., 2018a) because of its creative  
204 industry (Shan and Li, 2011), innovation atmosphere (Xie et al., 2018), and innovation  
205 performance (Xie, et al., 2011). For all these reasons, we expect the city chosen is a  
206 good exemplar to draw some exploratory conclusions on the effect of environmental  
207 regulations on urban green innovation.

### 208 **3.2 Urban green innovation efficiency analysis with SBM-DDF**

209 Data Envelopment Analysis (DEA) has been used for the analysis of production  
210 efficiency, as it is capable of handling multiple inputs and outputs (Zhang et al., 2011).  
211 Many studies have used DEA to analyze environmental pollution and energy  
212 consumption, mostly considering them as inputs (Reinhard et al., 1999) or undesirable  
213 outputs (Sueyoshi and Goto, 2013), and frequently with the intention of measuring  
214 efficiency under particular environmental constraints (Ramanathan, 2005).

215 Within DEA models, the direction distance function (DDF) is one of the most  
216 popular techniques. It allows considering the effects of desirable and undesirable  
217 outputs separately (Li et al., 2016; Pal and Mitra, 2016). More precisely, each Decision  
218 making unit (DMU) is assumed to get a set of  $M$  desirable outputs and  $K$  undesirable

219 outputs when  $N$  inputs are used.  $x$  refers to inputs,  $y$  and  $d$  are specific desirable and  
 220 undesirable outputs, whereas  $P(x)$  is defined as the set of production possibilities, which  
 221 is expressed as:

$$222 \quad P(x) = \{(x, y, d) : x \text{ produce } (y, d), \text{ with } x \in R_N^+, y \in R_M^+, d \in R_K^+\} \quad (1)$$

223 DDF can help increasing the desirable output and reducing the undesirable output  
 224 simultaneously (Chung et al., 1997). Particularly, letting directional vector  $g = (g_y, -g_d)$ ,  
 225  $\beta$  is the ratio of two types of outputs, giving:

$$226 \quad \vec{D}_0(x \square y \square d \square g) = \sup \{\beta : [(y \square d) + \beta g] \in P(x)\} \quad (2)$$

227 Furthermore, a slacks-based measure (SBM) model contains slack variables of  
 228 input and output. Based on research by Fukuyama and Weber (2009) and Färe et al.  
 229 (2007), SBM can be further combined with DDF to prevent DDF models' radial  
 230 character and directivity be effectively avoided. With this, a traditional DDF model's  
 231 overestimation of efficiency can be reduced (Li et al., 2018a; Arabi et al., 2015).

232 Hence, the slacks-based measure of directional distance functions (SBM-DDF)  
 233 considering undesirable outputs are defined as:

$$234 \quad \vec{D}_0^t(x^t, y^t, d^t, g^x, g^y, g^d) = \max_{s^x, s^y, s^d} \frac{\frac{1}{N} \sum_{n=1}^N \frac{s_n^x}{g_n^x} + \frac{1}{M+1} \left[ \sum_{m=1}^M \frac{s_m^y}{g_m^y} + \sum_{k=1}^K \frac{s_k^d}{g_k^d} \right]}{2} \quad (3)$$

$$235 \quad \text{s.t. } \sum_{j=1}^J z_j^t x_{jn}^t + s_n^t = x_{j,n}^t, \forall n; \sum_{j=1}^J z_j^t y_{jm}^t + s_m^t = x_{j,m}^t, \forall m;$$

$$236 \quad \sum_{j=1}^J z_j^t x_{jk}^t + s_k^t = x_{j,k}^t, \forall k; \sum_{j=1}^J z_j^t \geq 0, \forall j; s_n^x \geq 0, \forall n; s_m^y \geq 0, \forall m; s_k^d \geq 0, \forall k$$

237 Where  $j$  represents the number of decision-making units,  $z_j^t$  is the weight of period  
 238  $t$ , and  $(x^t, y^t, d^t) \square (g^x, g^y, g^d) \square (s^x, s^y, s^d)$  are the input-output, directional and  
 239 slack vectors, respectively.

### 240 3.3 Regression model construction

#### 241 3.3.1 Classic theory model

242 We will also resort to a regression model built on the STIRPAT model. The latter  
243 was proposed by Dietz and Rosa (1997) and has been widely used to study  
244 environmental pollution and economic development. The STIRPAT model is as follows:

$$245 \quad I = \alpha P^b A^c T^d e \quad (4)$$

246 The STIRPAT is a multivariate model, which involve the variables: population ( $P$ ),  
247 affluence ( $A$ ), and technology ( $T$ ). However, a logarithmic transformation of formula  
248 (4) is generally adopted:

$$249 \quad \ln I = \ln \alpha + b \ln P + c \ln A + d \ln T + \ln e \quad (5)$$

250 Where  $\alpha$  is a constant term;  $e$  is the error term; and  $b, c, d$  are the estimated terms.

251 This model can also be used for multivariate linear fitting.

#### 252 3.3.2 Extended model

253 Building on the model above, this study analyzes urban green innovation  
254 efficiency (UGIE) (as dependent variable) and adds different types of environmental  
255 regulations (independent variables) into the model.  $P$  is represented by the average  
256 number of higher education students;  $A$  is represented by the foreign direct investment;  
257 whereas  $T$  is the government investment in science and technology. All these are  
258 important factors affecting green innovation and will be duly justified later. In the model,  
259 they are treated as control variables.

260 With all this information, the first regression model will be:

$$261 \quad UGIE_t = \alpha + \beta_1 \ln CER_t + \beta_2 \ln MER_t + \beta_3 \ln VER_t + \beta_4 \ln CV_t + \varepsilon_t \quad (6)$$

262 Additionally, a quadratic term for the environmental regulation effects is added to  
263 explore the potential non-linear relationships between variables. This non-linear  
264 (quadratic) model is as follows:

265 
$$UGIE_t = \alpha + \beta_1 \ln ER_t + \beta_2 (\ln ER_t)^2 + \beta_3 \ln CV_t + \varepsilon_t \quad (7)$$

266 Where  $t$  presents the year ( $t$ =year 1, 2, 3...14);  $UGIE$  represents the urban green  
 267 innovation efficiency of Xi'an;  $\ln ER$  represents a specific type of environmental  
 268 regulation in Xi'an;  $\ln CER$  represents the command-and-control environmental  
 269 regulation;  $\ln MER$  represents the market-based environmental regulation;  $\ln VER$   
 270 represents the voluntary environmental regulation;  $\ln CV$  represents other control  
 271 variables;  $\alpha$  is the regression model intercept; and  $\varepsilon_t$  is a random error item. The way  
 272 all these variables are measured is explained in the next section.

273 **3.4 Regression variables**

274 **3.4.1 Urban green innovation efficiency (dependent variables)**

275 Different combinations of input and output variables may produce different  
 276 evaluation results (Song et al., 2015). This is why it is particularly important to build a  
 277 sound index system to evaluate green innovation. As Yuan and Xiang (2018) and Li et  
 278 al. (2016) did, urban green innovation efficiency is measured by establishing an index  
 279 system of multiple inputs and multiple outputs. They are summarized in Table 1.

280 **Table 1**

281 Index system summary of urban green innovation efficiency

Index	Index name	Measured by	Unit	Also adopted by (Source)
Input index	Labor input	R&D Personnel	Person	Li et al.(2018b) Kneller and Manderson (2012);
	Financial input	R&D expenditure	10,000 Yuan	Feng et al.(2017); Song et al.(2015)
	Resource input	Total gas supply in urban areas	Tons	Li and Wu(2016)
Desirable output index	Scientific and technological output	Number of granted invention patents	Units	Fankhauser et al. (2013); Yabar et al. (2013)
	Economic output	GDP per capita	Yuan/Person	Feng et al. (2017)
	Greening output	Green rate	%	Langemeyer et al.(2015)
Undesirable	Environmental output	SO <sub>2</sub> emissions	Tons	Managi and Kaneko (2006);

282 A thorough justification and further details of all the variables listed in Table 1 are  
283 presented as Supplemental Online material. For the sake of clarity and brevity, though,  
284 they have been left out of the main manuscript.

### 285 **3.4.2 Environmental regulations indices**

286 The indicators of *Command-and-control* environmental regulation generally  
287 include emission standards, laws, utilization and disposal rates, etc. However,  
288 environmental regulation laws and standards usually remain stable for long periods and  
289 cannot reflect changes shortly after new environmental regulations are introduced  
290 (Huang and Liu, 2014). Additionally, lack of reliable data concerning the standard rates  
291 of pollutants registered in Xi'an prevents this approach. Instead, following Xie et al.'s  
292 (2017) approach, the amount of environmental investments made by companies in  
293 environmental protection (pollution control mostly) is adopted.

294 *Market-based* environmental regulations are policy instruments (generally price  
295 and cost incentives) to encourage polluters to reduce or eliminate negative  
296 environmental externalities. Although cities in a few pilot provinces use environmental  
297 subsidies, market bonds, and emissions trading, Xi'an was not one of them. However,  
298 pollution discharge fee has been levied from 1982 and is therefore used to represent  
299 market-based regulations.

300 Finally, *Voluntary* environmental regulation aims at consciously protecting the  
301 environment and supervising companies and regulatory agencies through  
302 environmental information. Voluntary environmental regulations can be measured by  
303 environmental labels, environmental information disclosure, pollution complaints, etc.  
304 Here, following Kathuria (2007), we choose the number of environmental news items  
305 relating to environmental pollution to present voluntary environmental regulation.

### 306 **3.4.3 Control variables**

307 Many factors influence urban green innovation efficiency in addition to the three  
308 types of environmental regulation stated above. According to the research of Yuan and  
309 Xiang (2018) and Li et al. (2018b), control variables in this paper contain foreign direct  
310 investment, regional education level, and government support.

311 In the context of international openness and trade, the attraction of *foreign direct*  
312 *investment* (FDI) is highly desirable for developing countries (Newman et al., 2015).  
313 This investment is often accompanied by the adoption of new technologies and  
314 innovations, which can make up for the shortage of funds in the urban scientific and  
315 technological innovation landscape in the short run. The control variable FDI is  
316 therefore chosen in this study.

317 Education provides the human capital needed for a country's innovation system,  
318 which also encompasses green innovation. As the quality of university graduates is  
319 generally high (Yang et al., 2011), their number should fully reflect the level of local  
320 education. *Regional education level* is therefore represented by the amount of higher  
321 students (EDU), including undergraduate and postgraduate students studying in Xi'an.

322 *Government support* is crucial for the development of cities and its funding is  
323 irreplaceable in the process of innovation, as it reduces the cost and risk of research and  
324 stimulates R&D initiatives (Li et al., 2018a). This variable is therefore represented by  
325 government investment in science and technology (GIST).

### 326 **3.5 Real data collection**

327 According to Yin (2007), multiple sources of information strengthen the validity  
328 of a study. This study resorted to interviews, datasets, documents and reports from 2003  
329 to 2016 to study the efficiency of green innovation in Xi'an and the effect of different  
330 environmental regulations (data from 2017 onwards had not yet been all published as

331 of the submission of this manuscript). Namely:

332 (1) Datasets. Data on Xi'an's R&D personnel, total gas supply, R&D expenditure,  
333 number of granted invention patents, GDP per capita, green rate, SO<sub>2</sub> emissions,  
334 environmental investments in environmental protection, foreign direct investment,  
335 number of higher education students, and government investment were collected from  
336 Xi'an's statistical yearbooks (2004-2017) and the China city statistical yearbooks  
337 (2004-2017).

338 (2) Documents and reports. Data on pollution discharge fees and the number of  
339 environmental news items were obtained from the of Xi'an's ecology and environment  
340 bureau website (<http://xaepb.xa.gov.cn/ptl/index.html>), as well as from regional  
341 environmental reports.

342 (3) Interviews. This study also held some focus-group interviews to better  
343 understand some stakeholders' views on the role of different types of environmental  
344 regulations in Xi'an's green innovation. Rabiee (2004) pointed out that 6 to 8 people  
345 are generally the best choice for focus-groups interviews, thus six people were selected.  
346 Interviewees included government officials, business managers, scientific researchers,  
347 journalists and volunteers. The selection criteria of interviewees were the following:  
348 first, select the people closely related to Xi'an green development (for representativity  
349 purposes). Second, select the people from different industries and departments (for  
350 diversity purposes). Finally, choose people with minimum education level and working  
351 experience (for validity purposes). The collection methods of interview data were face-  
352 to-face recordings and notes in up to 90-minute interviews. The contents of these  
353 interview are summarized in Table 2.

354 **Table 2**

355 Summary of interviewees' profiles and interviews content



Number	Interviewee	Department	Working years	Educational background	Interview content highlights
#1	Government official	Municipal government	8 years	Postgraduate	At present, Xi'an's mandatory laws and regulations, incentive environmental policies can effectively promote the urban high-quality development. Xi'an's environmental governance and innovative development have made remarkable achievements.
#2	Government official	Ecology and environment	5 years	Postgraduate	Implement environmental supervision and law enforcement in Xi'an city, and impose administrative penalties on those who have environmental violations or fail to meet the emission standards, so as to promote the development of green innovation in Xi'an and build a greener, more innovative and ecological Xi'an.
#3	Business manager	Administration	3 years	Postgraduate	With the implementation of the government's incentive policy, enterprises have been encouraged to carry out green innovation, but independently from each other. However, this has resulted in greener technologies, and product and management innovation. It has significantly improved profits and productivity, and now enterprises have some absolute competitive advantages.
#4	Scientist	Technology innovation	4 years	Doctorate	Under the influence of environmental regulations, enterprises in Xi'an have increased the investment on technical personnel and capital to reduce pollutant emissions through technological innovation, and meet the standards requirements. Research on green innovative products is beneficial to both companies and the environment.
#5	Journalist	TV stations	6 years	Graduate	Media reports on the pollutant discharges of key urban pollutant enterprises, plus mass petition letters, visits and information disclosure, effectively curb urban pollution behavior.
#6	Volunteer	Organization volunteer	3 years	Graduate	Actively participating in volunteer activities related to environmental protection, and raising awareness of environmental protection, help Xi'an's citizens to promote and receive suggestions for urban green development.

## 356 4. Results

### 357 4.1 Urban green innovation efficiency

358 Implementing the SBM-DDF model, estimates of 2003-2016 green innovation  
359 efficiency are presented in Table 3. They were obtained using Maxdea® software. Table  
360 3 contains four headings: comprehensive efficiency, purely technological efficiency,  
361 scale efficiency, and return of scale. *Comprehensive efficiency* represents technical  
362 efficiency without considering returns of scale. It equals the scale efficiency multiplied  
363 by the purely technological efficiency. *Purely technological efficiency* reflects the

364 effectiveness of decision-making and management. *Scale efficiency* values are the result  
 365 of a change of scale. Finally, *return of scale* is used to analyze the changes in output  
 366 caused by the same proportion of internal production factors, which comprises three  
 367 situations (increasing, decreasing, and constant returns).

368 **Table 3**

369 Urban green innovation efficiency in Xi'an

Year	Comprehensive efficiency	Purely technological efficiency	Scale efficiency	Return of scale
2003	1.000	1.000	1.000	Constant
2004	1.000	1.000	1.000	Constant
2005	0.815	0.816	0.999	Decreasing
2006	1.000	1.000	1.000	Constant
2007	0.961	1.000	0.961	Decreasing
2008	1.000	1.000	1.000	Constant
2009	1.000	1.000	1.000	Constant
2010	1.000	1.000	1.000	Constant
2011	1.000	1.000	1.000	Constant
2012	0.841	0.849	0.990	Increasing
2013	1.000	1.000	1.000	Constant
2014	0.714	0.722	0.989	Increasing
2015	1.000	1.000	1.000	Constant
2016	1.000	1.000	1.000	Constant
Average	0.952	0.956	0.996	

370 As can be seen, the average comprehensive, purely technological, and scale  
 371 efficiency were 0.952, 0.956, and 0.996, respectively. The very high scale efficiency  
 372 evidences that the scale of green innovation activities was effective, and that returns  
 373 remain constant most years.

374 In 2003, 2004, 2006, 2008-2011, 2013, 2015, and 2016, comprehensive, purely  
 375 technological, and scale efficiency were all unity. This indicates that the input and  
 376 output of urban green innovations were at the front of the production frontier (input

377 resources fully utilized and optimal scale returns). In 2007, purely technological  
 378 efficiency was equal to unity, but the scale return decreased. That indicated that the  
 379 innovation foundation and practice were relatively mature at that time. However, the  
 380 scale was unreasonable and input and output were disproportionate. This meant a small  
 381 change in input was needed to cause an improvement in green innovation. In 2005,  
 382 2012, and 2014, purely technological efficiency was lower than scale efficiency, being  
 383 the impact of scale efficiency greater than technological efficiency.

## 384 4.2 Regression analysis

### 385 4.2.1 Unit root test

386 Phillips-Perron (PP) and Dickey-Fuller (DF) tests were used to analyze the data  
 387 stability of this study. Table 4 shows that all P values remained below 0.05. This rejects  
 388 the null hypothesis that there is a unit root in a time series sample, meaning all variables  
 389 can be deemed stable and that the data is suitable for empirical analysis.

390 **Table 4**

391 Unit root test results

Variables	Method	Statistic	P-value
UGIE	ADF	-4.6087	0.0039
	PP	-4.6231	0.0039
ln CER	ADF	-4.9093	0.0043
	PP	-12.4504	0.0000
ln MER	ADF	-4.3106	0.0074
	PP	-4.3929	0.0065
ln VER	ADF	-5.1788	0.0019
	PP	-5.6558	0.0009
ln FDI	ADF	-3.3268	0.0372
	PP	-7.7004	0.0001
ln EDU	ADF	-3.4608	0.0280
	PP	-3.4608	0.0280
ln GIST	ADF	-3.8718	0.0151
	PP	-5.0828	0.0022

392 **4.2.2 Regression results and analysis**

393 Tobit regression was necessary for expressions (6) and (7). Calculations were  
 394 carried out with Eviews 8® software, and Table 5 shows the regression analysis results  
 395 of the Tobit model.

396 **Table 5**

397 Regression analysis results

Index	Variables	Coefficient	Standard error	Z-value	P-value
Command-and-control env. reg.	ln CER	0.0022	0.0613	0.0351	0.9720
Market-based env. reg.	ln MER	0.1252*	0.0666	1.8810	0.0600
Voluntary environmental reg.	ln VER	0.4601***	0.1744	2.6382	0.0083
Foreign direct investment	ln FDI	0.2626*	0.1554	1.6905	0.0909
Regional education level	ln EDU	-1.9668***	0.7317	2.6880	0.0072
Government support	ln GIST	-0.0944	0.1387	0.6807	0.4961
Constant	$\alpha$	8.713***	3.0097	2.8949	0.0038

398 Note: \*\*\*, \*\*, and \* denotes significant levels of 1%, 5%, and 10% respectively

399 Table 4 shows that the P value of the variable ln CER is very high. Its regression  
 400 coefficient is very close to zero, indicating that the increase of command-and-control  
 401 environmental regulation neither stimulates nor inhibits urban green innovation  
 402 efficiency. Compared with command-and-control environmental regulation, the P value  
 403 of variable ln MER is 0.060 with a significance level of 0.1. Its positive coefficient  
 404 (0.1252) evidences a significant stimulating effect of market-based environmental  
 405 regulations on urban green innovation efficiency. Furthermore, among the  
 406 environmental regulations, voluntary regulations seem to have the most significant  
 407 impact (lowest P value too) on urban green innovation efficiency. Its coefficient (0.4601)  
 408 is comparatively larger than the previous two.

409 Concerning the impact of the other control variables, FDI significantly influences  
 410 green innovation (0.2626). Foreign enterprises use advanced production equipment,  
 411 technology, and management experience. Meanwhile, the city can effectively avoid the

412 negative crowding-out effect caused by the FDI with a strong economic and  
 413 technological foundation. Therefore, FDI can apparently improve green innovation  
 414 through imitation and competition.

415 The regional education level has a significant and negative effect (-1.9668).  
 416 Citizens and graduates do not seem to be consider the task of green innovation urgent,  
 417 nor there is a high demand for green development and technological improvement. All  
 418 this may have inhibited the development of green innovation in Xi'an.

419 The coefficient of government support is not significant, indicating that  
 420 government support does not have a significant impact. This may be due to the city's  
 421 weak green innovation power and its limited absorptive capacity. Alternatively, the  
 422 amount of government support may have been insufficient due to expenditure on other  
 423 innovative activities, further reducing overall investment in green innovation.

424 At the same time, we used the quadratic model from expression (7) to test other  
 425 non-linear relationships. Table 6 shows different non-linear regression analysis results  
 426 from models 1 to 3.

427 **Table 6**

428 Non-linear regression analysis results

Variables	Model 1	Model 2	Model 3
ln CER	3.5534**		
ln <sup>2</sup> (CER)	-0.1877**		
ln MER		2.7546***	
ln <sup>2</sup> (MER)		-0.1556***	
ln VER			7.3916*
ln <sup>2</sup> (VER)			-0.7149*
ln FDI	0.9168***	0.8682***	0.2027**
ln EDU	-2.4675***	-2.2582***	-0.2654
ln GIST	-0.1853	-0.0448	-0.1658
α	-7.7336	-5.5163	-16.7804
Curve type	Inverted U	Inverted U	Inverted U

Log likelihood	15.3276	19.0001	13.1247
----------------	---------	---------	---------

429 Note: \*\*\*, \*\*, and \* denotes significant levels of 1%, 5%, and 10% respectively

430 Model 1 contains linear and quadratic variables for command-and-control  
431 environmental regulations. Results indicates that coefficients of  $\ln(\text{CER})$  (linear term)  
432 is significant and positive while  $\ln^2(\text{CER})$  (quadratic term) is negative. This finding  
433 means that the relationship between environmental regulation and the efficiency of  
434 green innovation is an inverted U. This indicates that command-and-control  
435 environmental regulations stimulate green innovation in the initial stage (maybe  
436 because companies and institutions immediately react to new legal constraints and meet  
437 prescribed emission standards). However, when environmental regulation exceeds a  
438 certain level, obligations significantly increase the cost burden of environmental  
439 pollution control and its efficiency is reduced.

440 Model 2 shows that the coefficients of linear and quadratic terms are significantly  
441 positive and negative respectively, again showing the same inverted U-shape  
442 relationships as in model 1. Similarly, urban green innovation efficiency increases with  
443 the enforcement and improvement of market-based environmental regulations, but  
444 there is a progressive deterioration regarding its efficiency gains.

445 The coefficients of voluntary environmental regulation are both significant in  
446 Model 3, which again shows that voluntary environmental regulation has an inverted  
447 U-shaped effect on green innovation efficiency. It indicates that voluntary regulations  
448 are initially effective, but their effectiveness are also reduced as more voluntary  
449 regulations are passed over time.

450 Finally, as for control variables, FDI has a significant positive effect in Models 1  
451 and 2, while regional education level has a significant negative effect in all cases.

#### 452 **4.3 Robustness test**

453 In this study, we also implemented a series of robustness tests in the regression

454 models. Particularly, we used the robust least squares method to check whether the  
455 impacts of environmental regulation on green innovation had changed over time.

456 The robustness test results are shown in the Supplemental Online material. From  
457 their analysis it can be found that the regression results can be considered robust and  
458 data have remained relatively stable over the whole period of analysis.

## 459 **5. Discussion**

460 This study explores the linear and nonlinear relationships between three types of  
461 environmental regulations and green innovation efficiency at the city level of Xi'an.  
462 The results show that there is no direct impact of the type of regulation on green  
463 innovation efficiency in the linear analysis. However, it is found in the non-linear  
464 analyses, that the three types of environmental regulations are all intrinsically  
465 connected by means of inverted U-shape relationships with green innovation efficiency.

466 Particularly:

467 Command-and-control environmental regulation absence of linear correlation  
468 with green innovation efficiency is not consistent with the recent Zhang et al.'s (2018)  
469 analyses. However, the existence of a non-linear relationship might mean that when  
470 command-and-control regulations are implemented, companies and institutions usually  
471 rush into adopting new environmental strategies. They directly accept government-  
472 designated pollution reduction technologies and environmental standards, but lack  
473 freedom to choose the technologies they want to achieve those new goals (Song et al.,  
474 2013). Once they meet the emission reduction standards, companies regain freedom to  
475 choose how to keep reducing emissions (Pan et al., 2017). These effects tend to reduce  
476 the added value of innovative strategies and the investment of funds for scientific and  
477 technological innovation. Also, these unintended outcomes render the development and  
478 technological progress of cities more difficult, possibly mitigating the positive

479 environmental effects of enforcing this type of legislation.

480       Regarding market-based environmental regulation, their significant linear and  
481 non-linear connection with green innovation efficiency are in line with Jaffe et al.  
482 (2005). They found that environmental regulation, such as carbon emission trading  
483 system, taxes and so on, can incentivize technological change. Indeed, many scholars  
484 agree that this incentive-oriented policy has a more obvious promoting effect than the  
485 mandatory regulatory (Pan et al., 2017). This, because market-based environmental  
486 regulations are generally linked to product output restrictions and sewage discharge  
487 through taxes, fees, etc. This means regulatory costs are more reflected in the  
488 production process (Zhao and Sun, 2016; Zhang et al., 2018). Hence, under the  
489 influence of market-based environmental regulations, a city prioritizes the investments  
490 in better environmental technologies that meet the government's regulatory  
491 requirements. This balances their economic and environmental performance. In other  
492 words, market-based regulation produces strong innovation incentives that protect the  
493 environment more effectively. Market incentives can also better mobilize the  
494 enthusiasm of companies and institutions, and effectively combine their strengths to  
495 make decisions about the optimal input-output and pollution emissions (Zhao et al.,  
496 2015), but even those entities' innovation capabilities have some limits, which is why  
497 they decrease over time.

498       Lastly, the significant linear and non-linear relationship between voluntary  
499 environmental regulations and green innovation efficiency aligns with Cason and  
500 Seema's (2004) results. They found that public information and awareness is key to  
501 encourage companies to voluntarily reduce toxic substances release and improve their  
502 environmental performance. They also showed that green innovation efficiency can be  
503 more effectively stimulated by voluntary environmental regulations. The main reason



504 being that voluntary environmental regulation can not only alleviate regulatory pressure,  
505 but also invite enterprises and institutions to develop their own energy conservation and  
506 emission reduction plan (Lim and Prakash, 2014). The latter helps building a mutual  
507 trust between enterprises and regulators (Ball et al., 2018). However, this kind of  
508 regulation also has a spillover effect. When it exceeds a certain level, the investment of  
509 enterprises comes to a limit and the promotion effect is reduced.

## 510 **6. Policy recommendations**

511 According to the results and discussions of this study, policy makers should  
512 understand the different levels of effectiveness of these regulations and optimize them  
513 so as to make better-informed decisions. Mandatory command-and-control  
514 environmental regulation will lead to a lack of options for green innovation  
515 technologies for companies, while market-based environmental regulation takes into  
516 account emission reduction costs and encourages companies to adequately allocate  
517 resources in the market. This means economic instruments are more conducive to green  
518 innovation than setting compulsory environmental standards and emission limits.  
519 Policy makers could actively apply market-based environmental regulations to improve  
520 the market platform of regional industries and promote pilot trials of new emission taxes  
521 and carbon trading to ultimately achieve greater pollution control.

## 522 **7. Conclusion**

523 It is necessary to encourage green innovation by effectively designing  
524 environmental regulations that stimulate urban green transformation. With the case  
525 study of Xi'an, this study analyses the changes and influences of three environmental  
526 regulations on urban green innovation. Results show that command-and-control  
527 environmental regulations restrain the growth of green innovation, mostly because of  
528 their implementation costs. Market-based and voluntary environmental regulations, on

529 the other hand, significantly stimulate green innovation efficiency. With improvement  
530 of market mechanisms, and particularly by increasing the environmental awareness of  
531 companies and public, voluntary environmental regulations have the most noticeable  
532 incentivizing linear effect on green innovation. The three types of environmental  
533 regulations also have an inverted U relationship with green innovation efficiency.  
534 Finally, considering other factors influencing urban green innovation, it is found that  
535 the level of regional education is significantly but inversely correlated with green  
536 innovation efficiency, international openness is positively and significantly correlated,  
537 whereas government support has no significant impact.

538 The theoretical contribution of this study lies in, firstly, focusing on the effect of  
539 environmental regulations on green innovation at the urban level in the developing  
540 country like China. Secondly, understanding the non-linear effects of three  
541 environmental regulations on urban green innovation efficiency.

542 There are also some limitations to be considered. First, due to the unavailability of  
543 some statistical data from the early years in the time series analyzed, the analysis of the  
544 link between environmental regulations and green innovation is not exhaustive.  
545 Secondly, the input and output factors of urban green innovation and the environmental  
546 factors used in this study as regression variables are complex and multifaceted factors.  
547 A simplified approach was adopted here to represent their major traits with the  
548 information available. In future research, more environmental variables may be needed  
549 to increase the model's reliability and accuracy.

## 550 **References**

- 551 Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2013). The porter hypothesis at 20: can  
552 environmental regulation enhance innovation and competitiveness? *Review of*  
553 *Environmental Economics and Policy*, 7(1), 2-22.
- 554 Arabi, B., Munisamy, S., & Emrouznejad, A. (2015). A new slacks-based measure of  
555 Malmquist–Luenberger index in the presence of undesirable outputs. *Omega*, 51, 29-37.

556 Bai, C.L. (2012). Leading China's Sustainable Development by Meeting Global Challenges and  
557 Achieving Green Innovation. *Bulletin of the Chinese Academy of Sciences*, 26(3), 176-182.

558 Ball, C., Burt, G., De Vries, F., & MacEachern, E. (2018). How environmental protection  
559 agencies can promote eco-innovation: The prospect of voluntary reciprocal legitimacy.  
560 *Technological Forecasting and Social Change*, 129, 242–253.

561 Bergek, A., & Berggren, C. (2014). The impact of environmental policy instruments on  
562 innovation: a review of energy and automotive industry studies. *Ecological Economics*,  
563 106, 112-123.

564 Bibri, S. E. (2015). The Shaping of Ambient Intelligence and the Internet of Things: Historico-  
565 epistemic, Socio-cultural, Politico-institutional and Eco-environmental Dimensions.  
566 Atlantis: Atlantis press.

567 Bibri, S. E., Krogstie, J. (2016). On the social shaping dimensions of smart sustainable cities: a  
568 study in science, technology, and society. *Sustainable Cities and Society*,  
569 doi:10.1016/j.scs.2016.11.004.

570 Borsatto, J.M.L. S., & Amui, L.B.L. (2019). Green innovation: Unfolding the relation with  
571 environmental regulations and competitiveness. *Resources, Conservation and Recycling*,  
572 149, 445–454.

573 Cason, T., Seema, A., 2004. An experiment in voluntary environmental regulation: participation  
574 in EPA's 33/50 program. *Journal of Environmental Economics & Management*. 28(3),  
575 271-286.

576 CCICED, 2008. Harmonious Development through Innovation. China Council for International  
577 Cooperation on Environment and Development, Beijing. [http:// www. cciced. net](http://www.cciced.net/cciceden/)  
578 /cciceden/ accessed 20 September 2018.

579 Chen, S., Härdle, W. K., 2015. Dynamic activity analysis model-based win-win development  
580 forecasting under environment regulations in China. *Computational Statistics*. 30(4),1-1.

581 Chen, Y.S., Lai, S.B., Wen, C.T., 2006. The influence of green innovation performance on  
582 corporate advantage in Taiwan. *Journal of Business Ethics*. 67(4), 331-339.

583 [dataset] China, N. B. o. S., Xi'an, M. B. o. S., 2004-2017. Xi'an statistical yearbook. China  
584 Statistics Press, Beijing.

585 [dataset] China, N. B. o. S., 2004-2017. China city statistical yearbook. China Statistics Press,  
586 Beijing.

587 Chung, Y.H.H., Färe, R., Grosskopf, S., 1997. Productivity and undesirable outputs: A  
588 directional distance function approach. *Microeconomics*. 51(3), 229-240.

589 Cumo, F., Astiaso Garcia, D., Calcagnini, L., Cumo, F., Rosa, F., & Sferra, A. S., 2012. Urban  
590 policies and sustainable energy management. *Sustainable Cities and Society*, 4, 29–34.

591 Dong, L., Gu, F.M., Fujita, T., et al., 2014. Uncovering opportunity of low-carbon city  
592 promotion with industrial system innovation: Case study on industrial symbiosis projects

593 in China. *Energy Policy*. 65(3), 388-397.

594 Driessen, P. H., Hillebrand, B., 2002. Adoption and diffusion of green innovations. *Marketing*  
595 *for Sustainability: Towards Transactional Policy-Making*. 343-355. Amsterdam: IOS Press.

596 Eisenhardt, K. M., 1989. Building Theories from Case Study Research. *Academy of*  
597 *management journal*. 14. (4), 532-550.

598 Fankhauser, S., A. Bowen, R. Calel, A., et al., 2013. "Who will win the green race? In search  
599 of environmental competitiveness and innovation." *Global Environmental Change*. 23(5),  
600 902-913.

601 Färe, R., Grosskopf, S., Pasurka, C.A., 2007. Environmental production functions and  
602 environmental directional distance functions. *Energy*. 32(7), 1055-1066.

603 Fei, J., Wang, Y., Yang, Y., et al., 2016. Towards eco-city: The role of green innovation. *Energy*  
604 *Procedia*. 104, 165-170.

605 Feng, C., Shi, B., Kang, R., 2017. Does environmental policy reduce enterprise innovation?—  
606 Evidence from China. *Sustainability*. 9(6), 872.

607 Fukuyama, H., Weber, W. L., 2009. A directional slacks-based measure of technical inefficiency.  
608 *Socio-Economic Planning Sciences*. 43(4), 274-287.

609 Fussler, C., James, P., 1996. *Driving co-Innovation: A Break Thorough Discipline for*  
610 *Innovation and Sustainability*. Pitman Publishing, London.

611 Glaeser, E. L., Kahn, M. E., 2010. The greenness of cities: carbon dioxide emissions and urban  
612 development. *Journal of Urban Economics*. 67(3), 404-418.

613 Guo, Q., Zhou, M., Liu, N., Wang, Y., 2019. Spatial Effects of Environmental Regulation and  
614 Green Credits on Green Technology Innovation Under Low-Carbon Economy  
615 Background Conditions. *International Journal of Environmental Research and Public*  
616 *Health*, 16(17), 3027.

617 Huang, Y., Liu, L., 2014. Fighting corruption: A long-standing challenge for environmental  
618 regulation in China. *Environmental Development*. 12, 47-49.

619 Huang, M.X., 2018. *China Urban Innovation Competitiveness Development Report*. Social  
620 *Sciences Academic Press*, Beijing.

621 Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: Technology and  
622 environmental policy. *Ecological Economics*. 54(2-3), 164-174.

623 Ji, Q., Li, C., Jones, P., 2017. New green theories of urban development in China. *Sustainable*  
624 *Cities and Society*, 30, 248–253.

625 Kathuria, V., 2007. Informal regulation of pollution in a developing country: evidence from  
626 India. *Ecological Economics*. 63(2-3), 403-417.

627 Kemp, R., Arundel, A., Smith, K., 1998. Survey indicators for environmental innovation.  
628 Garmisch-Partenkirchen. Conference towards environmental innovation systems,

629 Germany.

630 Khan, Z., Sisi, Z., Siqun, Y., 2019. Environmental regulations an option: Asymmetry effect of  
631 environmental regulations on carbon emissions using non-linear ARDL. *Energy Sources,*  
632 *Part A: Recovery, Utilization, and Environmental Effects*, 41:2, 137-155.

633 Kneller, R., Manderson, E., 2012. Environmental regulations and innovation activity in UK  
634 manufacturing industries. *Resource & Energy Economics*. 34(2), 211-235.

635 Langemeyer, J., Baró, F., Roebeling, P., et al., 2015. Contrasting values of cultural ecosystem  
636 services in urban areas: the case of park Montjuïc in Barcelona. *Ecosystem Services*. 12,  
637 178-186.

638 Li, B., Wu, S., 2016. Effects of local and civil environmental regulation on green total factor  
639 productivity in China: A spatial Durbin econometric analysis. *Journal of Cleaner*  
640 *Production*. 153.

641 Li, H., Zhang, J., Osei, E., Yu, M., 2018a. Sustainable development of China's industrial  
642 economy: an empirical study of the period 2001–2011. *Sustainability*. 10(3), 764.

643 Li, H., Zhang, J., Wang, C., et al., 2018b. An evaluation of the impact of environmental  
644 regulation on the efficiency of technology innovation using the combined DEA model: A  
645 case study of Xi'an, China. *Sustainable Cities and Society*. 42, 355-369.

646 Liao, Z.J., 2018. Content analysis of China's environmental policy instruments on promoting  
647 firms' environmental innovation. *Environmental Science & Policy*. 88: 46-51.

648 Lim, S., Prakash, A., 2014. Voluntary regulations and innovation: the case of ISO 14001. *Public*  
649 *Administration Review*. 74(2), 233-244.

650 Liu, G., 2015. Evaluating the regional green innovation efficiency in China: a DEA-Malmquist  
651 productivity index approach. *Applied Mechanics and Materials*. 733, 355-362.

652 Managi, S., Kaneko, S., 2006. Economic growth and the environment in China: an empirical  
653 analysis of productivity. *International Journal of Global Environmental Issues*. 6(1), 89-  
654 133.

655 Mejia, R., 2009. The challenge of environmental regulation in India. *Environmental Science &*  
656 *Technology*. 43(23), 8714-8715.

657 Meng, X.Y., 2018. Chinese city innovation ranking report in 2018. [http:// www.sohu.com /a/  
658 277194735\\_348961 /](http://www.sohu.com/a/277194735_348961/)accessed 03 December 2018.

659 Mickwitz, P., Heli Hyvättinen, Kivimaa, P., 2008. The role of policy instruments in the  
660 innovation and diffusion of environmentally friendlier technologies: popular claims versus  
661 case study experiences. *Journal of Cleaner Production*. 16(1), S162-S170.

662 Morris, A., Zuo, J., Wang, Y., Wang, J., 2018. Readiness for sustainable community: A case  
663 study of Green Star Communities. *Journal of Cleaner Production*. 173, 308-317.

664 Nesta, L., Vona, F., Nicolli, F., 2012. Environmental policies, product market regulation and  
665 innovation in renewable energy. *SSRN Electronic Journal*. 234(6), 120-141.

666 Newman, C., Rand, J., Talbot, T., Tarp, F., 2015. Technology transfers, foreign investment and  
667 productivity spillovers. *European Economic Review*. 76, 168-187.

668 OECD, 2011. Fostering innovation for green growth. Source *OECD Environment &*  
669 *Sustainable Development*. 12, 108-119.

670 Pal, D., Mitra, S. K., 2016. An application of the directional distance function with the number  
671 of accidents as an undesirable output to measure the technical efficiency of state road  
672 transport in India. *Transportation Research Part A Policy & Practice*. 93, 1-12.

673 Pan, X., Ai, B., Li, C., Pan, X., & Yan, Y., 2017. Dynamic relationship among environmental  
674 regulation, technological innovation and energy efficiency based on large scale provincial  
675 panel data in China. *Technological Forecasting and Social Change*.

676 Rabiee, F., 2004. Focus-group interview and data analysis. *Proceedings of the Nutrition Society*.  
677 63(04), 655-660.

678 Ramanathan, R., 2005. An analysis of energy consumption and carbon dioxide emissions in  
679 countries of the Middle East and North Africa. *Energy*. 30(15), 0-0.

680 Reinhard, S., Lovell, C.A.K., Thijssen, G., 1999. Econometric estimation of technical and  
681 environmental efficiency: an application to Dutch dairy farms. *American Journal of*  
682 *Agricultural Economics*. 81, 44–60.

683 Ren, S., Li, X., Yuan, B., et al., 2016. The effects of three types of environmental regulation on  
684 eco-efficiency: A cross-region analysis in China. *Journal of Cleaner Production*. 173, 245-  
685 255.

686 Ribeiro, Flávio de Miranda, Kruglianskas, I., 2015. Principles of environmental regulatory  
687 quality: a synthesis from literature review. *Journal of Cleaner Production*. 96, 58-76.

688 Ryan, R.L., 2018. Green infrastructure planning on campus: case studies from university of  
689 massachusetts-amerst. *Journal of Green Building*. 13(3), 145-157.

690 Schiederig, T., Tietze, F., Herstatt, C., 2012. Green innovation in technology and innovation  
691 management – an exploratory literature review. *R&D Management*. 42(2), 180-192.

692 Shan, J., Li, H., 2011. Intellectual property protection of Xi'an creative industries. 2011  
693 International Conference on Business Management and Electronic Information.

694 Song, M., Tao, J., Wang, S., 2015. FDI, technology spillovers and green innovation in China:  
695 analysis based on Data Envelopment Analysis. *Annals of Operations Research*. 228(1),  
696 47-64.

697 Song, M., Zhang, L., An, Q., Wang, Z., Li, Z., 2013. Statistical analysis and combination  
698 forecasting of environmental efficiency and its influential factors since china entered the  
699 wto: 2002–2010–2012. *Journal of Cleaner Production*, 42, 42-51.

700 Sueyoshi, T., Goto, M., 2013. Returns to scale vs. damages to scale in data envelopment  
701 analysis: an impact of U.S. clean air act on coal-fired power plants. *Omega*. 41(2), 164-  
702 175.

703 Sum, N.L., 2005. Towards a cultural political economy: Discourses, material power and  
704 (counter-) hegemony. EU Framework 6 DEMOLOGOS SPOT PAPER.

705 Sun, C., Tong, Y., Zou, W., 2018. The evolution and a temporal-spatial difference analysis of  
706 green development in China. *Sustainable Cities and Society*, 41, 52-61.

707 Tang, J., Zhong, S.H., Xiang, G.C., 2019. Environmental Regulation, Directed Technical  
708 Change, and Economic Growth: Theoretic Model and Evidence from China. *International  
709 Regional Science Review*, 42(5-6), 519-49.

710 Wang, C., Zhang, Y., 2019. Does environmental regulation policy help improve green  
711 production performance? Evidence from China' s industry. *Corporate Social  
712 Responsibility and Environmental Management*. DOI: 10.1002/csr.1857

713 Wang, Y., Zhou, Y., 2015. The Empirical Analysis of Technological Innovation Efficiency of  
714 Small and Medium-Sized High-Tech Enterprises in Xi'an High-Tech Zone Based on DEA.  
715 *Advanced Materials Research*. 1065-1069, 2495-2499.

716 Xie, R., Yuan, Y., Huang, J., 2017. Different types of environmental regulations and  
717 heterogeneous influence on "green" productivity: Evidence from China. *Ecological  
718 Economics*. 132, 104-112.

719 Xie, Y., Xue, W., Li, L., et al., 2018. Leadership style and innovation atmosphere in enterprises:  
720 An empirical study. *Technological Forecasting and Social Change*.

721 Xie, Y., Mao, Y., Zhang, H., 2011. Analysis of Influence of Network Structure, Knowledge  
722 Stock and Absorptive Capacity on Network Innovation Achievements. *Energy Procedia*.  
723 5, 2015–2019.

724 Yabar, H., Uwasu, M., Hara, K., 2013. Tracking environmental innovations and policy  
725 regulations in Japan: case studies on dioxin emissions and electric home appliances  
726 recycling. *Journal of Cleaner Production*. 44, 152-158.

727 Yang, T., Wang, N., 2009. Urban Innovation Based on the Environmental Management.  
728 *International Conference on Environmental Science & Information Application  
729 Technology*. IEEE Computer Society.

730 Yang, Z., Zhang, Y., Rong, R., Zou, X., 2011. The multi-level fuzzy evaluation model of college  
731 students' comprehensive quality. *International Conference on Information Science &  
732 Engineering*. IEEE.

733 Yin, R., 2007. *Case study research: Design and methods* (Fourth edition). Sage publications.

734 Yu, T., Shi, Q., Zuo, J., Chen, R., 2018. Critical factors for implementing sustainable  
735 construction practice in HOPSCA projects: A case study in China. *Sustainable cities and  
736 society*. 37, 93-103.

737 Yuan, B., Ren, S., Hu, X., Yang, X., 2016. The difference effect of environmental regulation on  
738 two stages of technology innovation in china's manufacturing industry. *Frontiers of*

739           Engineering Management. 3(1), 24.

740 Yuan, B., Xiang, Q., 2018. Environmental regulation, industrial innovation and green  
741           development of Chinese manufacturing: based on an extended CDM model. *Journal of*  
742           *Cleaner Production*. 176, 895-908.

743 Zhang, C., Liu, H., Bressers, H.T.A, et al., 2011. Productivity growth and environmental  
744           regulations - accounting for undesirable outputs: Analysis of China's thirty provincial  
745           regions using the Malmquist–Luenberger index. *Ecological Economics*. 70(12), 2369-  
746           2379.

747 Zhang, Y., Wang, J., Xue, Y., Yang, J., 2018. Impact of environmental regulations on green  
748           technological innovative behavior: an empirical study in china. *Journal of Cleaner*  
749           *Production*. 188, 763-773.

750 Zhao, X., Zhao, Y., Zeng, S., et al., 2015. Corporate behavior and competitiveness: impact of  
751           environmental regulation on Chinese firms. *Journal of Cleaner Production*. 86, 311-322.

752 Zhao, X., Sun, B., 2016. The influence of Chinese environmental regulation on corporation  
753           innovation and competitiveness. *Journal of Cleaner Production*. 112(4), 1528-1536.

754 Zuo, J., Read, B., Pullen, S., Shi, Q., 2012. Achieving carbon neutrality in commercial building  
755           developments-Perceptions of the construction industry. *Habitat International*. 36(2), 278-  
756           286.